CGMS-XXVIII
WMO WP-14
Prepared by WMO
Agenda item: D.1

GLOBAL PLANNING, INCLUDING ORBITAL POSITIONS

(*Submitted by WMO*)

Summary and purpose of document

This document presents a discussion on the present orbital positions for the satellites within the space-based Global Observing System (GOS) as well as the emerging need to include Research & Development (R&D) satellites in the space-based GOS.

ACTION PROPOSED:

CGMS may wish to consider and comment on the suggestions contained in the document.

DISCUSSION

The following discussion is based on a paper presented at the EUMETSAT User Conference held in Bologna, Italy in May 2000. The paper traced the history of the space-based Global Observing System (GOS), its present configuration and a possible expansion to include several new mission areas.

Background

The Global Observing System was established during the formation of the World Meteorological Organization (WMO) World Weather Watch (WWW). During the nearly four decades since the formation of the WWW, the space component of the GOS has evolved from a constellation of one or more polar-orbiting meteorological satellites to two constellations comprised of at least two near-polar-orbiting satellites and at least five geostationary environmental observation satellites. The space-based GOS has benefited from and responded to three primary factors: space agency plans; technology; and user requirements. Each of these factors has been a good indicator of what is probable, possible and required, respectively. These factors, pillars of the GOS, have developed and evolved at different rates during the lifetime of the GOS.

Historical Review of the Global Observing System

When the WWW was first established, one of the new observing system's main requirements was the continuous existence of one or more satellites. At that time, only polar-orbiting satellites existed and the space-based GOS needed only one or more such satellites.

CGMS may recall that the ***WMO, WWW, The Plan and Implementation Programme, May 1967*** stated that WMO should act as a catalyst in bringing about coordination of the satellite programmes of individual countries (or groups of countries). Thus, one finds reference to the need for a coordination group articulated by WMO to the satellite operators. In 1972, CGMS was formed.

The year 1971 was a watershed for satellite meteorology and the space-based GOS because of a recent and dramatic development in satellite meteorology. In 1966, a technology demonstration communications satellite, ATS-1, flew in geostationary orbit with a meteorological payload. The ***WMO, WWW, The Plan and Implementation Programme, 1972-1975***, ***July 1971*** contained a new and more formal description of the space-based GOS as follows:

> Meteorological satellites can be divided into two groups, those in polar or near-polar orbits and those in geostationary orbit. With the former it is possible to choose the orbit altitude within a wide range, while with the latter it must be approximately 37,000 km. A satellite in near-polar orbit at an altitude of, say 1,000 km, has a big advantage over a geostationary satellite as regards the resolution that can be obtained with a particular optical system. The near-polar orbiting satellite has the further advantage of being able to observe the whole globe whereas a geostationary satellite can only provide useful cloud cover information in an area within a range of about 60-65 degrees from the sub-satellite point;
>
> To provide reasonably complete coverage in the tropics for wind determination from cloud displacement measurements, four geostationary satellite are necessary. These satellites should be capable of taking cloud observations between about 50°N and 50°S at short-time intervals both by day and by night.
>
> According to the latest information available, there will be two or three near-polar orbiting meteorological satellites in continuous operation during the period 1972-1975. This number should be adequate to meet the needs of the GOS. [7]

By 1977, the space-based GOS was well established in terms of plans and implementation. The introductory chapter for the ***WMO, WWW, Planning Report No. 36, The Role of Satellites in WMO Programmes in the 1980s, 1977 by D.S. Johnson and I.P. Vetlov*** heralded an impending change of major significance.

> "Until quite recently this early planning for WWW served as a useful guide for the development of a global satellite observing system. However, satellites will soon play a far greater role than was originally anticipated in 1961. Satellites will play an increasingly important role not only in obtaining observational data, but also in providing a capacity for the collection and distribution of information in support of various WMO programmes." [15]

The defining phrase "in support of various WMO programmes" greatly extended the scope of responsibility for the space-based GOS. Not only the WWW but also almost all WMO programmes would be served. This expansion would require a review of the then definition of the space-based GOS. Johnson and Vetlov would propose a possible constellation of satellites to be a system consisting of three to four satellites in quasi-polar orbits and four to five geostationary satellites in equatorial orbits. From a system point of view, the polar-orbiting satellites would have a primary role in providing global sounding data and high-resolution surface observations, especially those required for specialized applications programmes. The spacecraft in geostationary orbit would be used primarily for continuous monitoring of clouds for short-period and mesoscale forecasting and storm warnings, and to obtain winds at two or three levels in the troposphere. [15]

The latest and formal description of the space-based GOS can be found in the 1993 edition of the Manual for the GOS which notes the need for a system of at least two near-polar-orbiting satellites and at least five geostationary environmental observation satellites. Here an environmental observation satellite was defined as "An artificial Earth satellite providing data on the Earth System which are of benefit to WMO Programmes. These data support a variety of disciplines including, but not limited to, meteorology, hydrology, climatology, oceanography, climate and global change related disciplines."

The 1993 edition of the Manual for the Global Observing System also contains a definition for an experimental satellite:

> "An environmental observation satellite with the primary purpose of acquiring a defined set of research data; testing new instrumentation and/or improving existing sensors and satellite systems; and/or it may provide information for operational use, but has limitations due to the lack of a commitment to ensure continuity of service or a reliable satellite replacement policy; and also due to non-consistent modes of operations."

As can be seen, the definition includes the experimental satellites as part of the space-based GOS. However, at present, the recognized group of satellite providers for the space-based GOS only includes meteorological satellite operators.

The present space-based Global Observing System

There are two major constellations in the current space-based GOS (see Figure 1). One constellation is the various geostationary satellites, which operate in an equatorial belt and provide a continuous view of the weather from roughly 70°N to 70°S. At present there are satellites at 0° longitude and 63°E (operated by the European Organisation for the Exploitation of Meteorological Satellites - EUMETSAT), a satellite at 76°E (operated by the Russian Federation), a satellite at 105°E (operated by the People's Republic of China), a satellite at 140°E (operated by Japan), and satellites at 135°W and 75°W (operated by the USA).

The second constellation in the current space-based GOS comprises the polar-orbiting satellites operated by the Russian Federation, the USA and the People's Republic of China. The METEOR-3 series has been operated by the Russian Federation since l991. The polar satellite operated by the USA is an evolutionary development of the TIROS satellite, first launched in April l960. The present NOAA series, based on the TIROS-N system, has been operated by the USA since l978. FY-1C, the third in the series of China's polar-orbiting satellites, is now operational. These spacecraft provide coverage of the Polar Regions beyond the view of the geostationary satellites and fly at altitudes of 850 to 900 km.

The ability of geostationary satellites to provide a continuous view of weather systems make them invaluable in following the motion, development, and decay of such phenomena. Even such short-term events such as severe thunderstorms, with a lifetime of only a few hours, can be successfully recognized in their early stages and appropriate warnings of the time and area of their maximum impact can be expeditiously provided to the general public. For this reason, its warning capability has been the primary justification for the geostationary spacecraft. Since 71 per cent of the Earth's surface is water and even the land areas have many regions which are sparsely inhabited, the polar-orbiting satellite system provides the data needed to compensate the deficiencies in conventional observing networks. Flying in a near-polar orbit, the spacecraft is able to acquire data from all parts of the globe in the course of a series of successive revolutions. For these reasons the polar-orbiting satellites are principally used to obtain: (a) daily global cloud cover; and (b) accurate quantitative measurements of surface temperature and of the vertical variation of temperature and water vapour in the atmosphere. There is a distinct advantage in receiving global data acquired by a single set of observing sensors. Together, the polar-orbiting and geostationary satellites constitute a truly global meteorological satellite network.

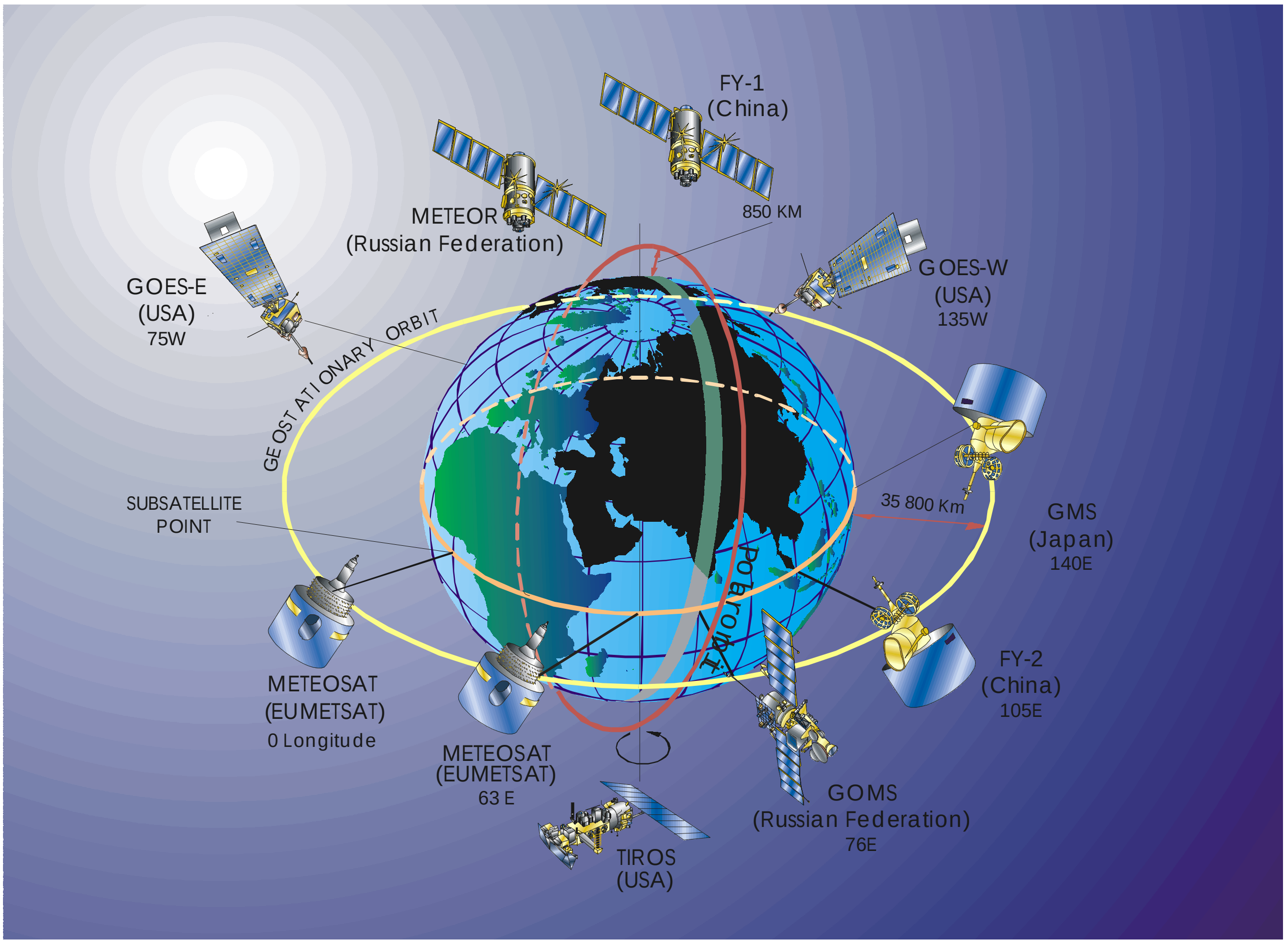


Figure 1 – The present configuration for the space-based Global Observing System

The future space-based Global Observing System

Four important events have occurred since 1998 that have direct relevance to the future of the space-based GOS.

Firstly, the Commission for Basic Systems at its Extraordinary Session in 1998 recognized the need to review and update the GOS. Specifically, it tasked its Open Programme Area Group on Integrated Observing Systems (OPAG IOS) to:

(i) Assess the capabilities of new observing systems or improvements of those existing, in particular with a view to reducing deficiencies in the existing GOS;

(ii) Prepare and maintain reviews of impact assessments conducted by the Global Data Processing System and other Numerical Weather Prediction (NWP) centres under programme activities that are relevant to the design and implementation of composite observing systems;

(iii) Prepare and maintain reviews of surface-based and space-based observing systems, (including radar and remote sensing systems) that are candidate components of the future composite GOS;

(iv) Study hypothetical changes to the GOS, prepare a prioritized list of proposals which are both practicable and amenable to testing and suggest mechanisms for testing them;

(v) Prepare report on impact and benefits of satellite data in NWP (linked to OSSEs);

A dedicated team of experts armed with user data requirements and knowledge of the expected performances of both space-based and *in situ* observing systems and using sophisticated analysis tools has endeavoured to provide CBS with recommendations in response to the 1998 tasking. Their efforts are nearing fruition and have already produced two technical documents that provide guidance to both the users and providers as to the evolution of the GOS. Another technical document is in preparation (See WMO WP-8).

Secondly, the Twenty-seventh session of the Coordination Group for Meteorological Satellites, held in Beijing, China, 13-18 October 1999 discussed the present configuration of the space-based GOS. During the discussion, the compliance of the space-based GOS in the post 2010 era was reviewed in the context of the present user requirements. In particular, CGMS addressed two interleaved issues:

(1) whether important gaps would exist in the post 2010 space-based GOS and how could they be filled; and,

(2) how to better optimize the present configuration of the space-based GOS including already planned and approved components in the 2000-2010 period.

CGMS was of the opinion that the discussion highlighted the need for a more strategic overview of the present space-based GOS. CGMS recalled that the GOS had originally been designed in the 1960s composed of 2-3 polar–orbiting and 4-5 geostationary meteorological satellites provided by the CGMS satellite operators primarily in response to meteorological observational requirements. The original 1960s design had been only realized during the decade of the 1990’s. During this evolution, new and key observational requirements of WMO operational and research programmes and other established Earth observation programmes had emerged that were beyond the capabilities of the current satellite observing systems.

CGMS felt that the time was most opportune to consider more comprehensively the future development of the space-based GOS. The future design had to take account of operational requirements, e.g., operational continuity and multiplicity of observation, including orbit characteristics, equator crossing times, together with contingency planning at the level of both spacecraft and instrument. The new observing system had not only to take account of planned meteorological satellites but also research and other Earth observation satellite systems including a coherent and planned transition from research to operational status especially for new and emerging technologies. CGMS also realized that the space-based GOS could well be comprised of several multi-purpose and multi-operator satellites as well as smaller single or limited purpose satellites. CGMS was of the opinion that a total redesign of the space-based component of the GOS was not envisioned but rather a progressive and planned evolution.

Thirdly, the WMO Executive Council convened a high level meeting in January 2000 (See WMO WP-15 for more details) between the satellite operators and senior representatives of the WMO user community. The purpose of the meeting was to investigate the need and feasibility for high level interactions between WMO and the satellite operators. Participants of the meeting were of the opinion that a need did exist for high-level policy discussions and that such discussions would be mutually beneficial. Furthermore, they agreed that a mechanism for such discussions could be provided through the convening of "Consultative Meetings on High-Level Policy on Satellite Matters" at one to two year intervals. An initial list of topics was proposed as well as two specific recommendations for early consideration as follows:

- Evaluate satellite missions to ensure, *inter alia*, the better use of existing and planned R&D missions in support of WMO Programmes and provide an assessment on their operational utility;

- Review and revise the space-based component of the GOS to take into account both operational and R&D opportunities and the need to maximize cost efficiency and effectiveness of satellite observing programmes.

Fourthly, WMO became a Partner within the Integrated Global Observing Strategy (IGOS). IGOS seeks to provide a comprehensive framework to harmonize the common interests of the major space-based and *in-situ* systems for global observation of the Earth. It is being developed as an over-arching strategy for conducting observations relating to climate and atmosphere, oceans and coasts, the land surface and the Earth’s interior. IGOS strives to build upon the strategies of existing international global observing programmes, and upon current achievements. It seeks to improve observing capacity and deliver observations in a cost-effective and timely fashion. The IGOS Partnership currently fulfills its role primarily through a “theme’ approach to defining an IGOS. The theme approach recognizes that in reality it is impossible in one step to complete the exercise of defining all the necessary observational requirements and hence the observational systems, data handling, processing and analysis infrastructure for a comprehensive global system. The theme approach allows for a coherent definition and development of an overall global strategy whilst recognizing the different state and stage of development in different areas. The first IGOS theme selected is the Oceans Theme and the second the Terrestrial Carbon Cycle Theme. It is anticipated that a Global Carbon Cycle Theme will evolve in the near future. Other proposed but not yet approved themes include the Water Cycle and Atmospheric Chemistry.

The three-pillar vantage point provides a methodology for proposing a possible future configuration of the space-based GOS. The methodology requires one to evaluate each pillar to determine: if a user requirement exists for a particular parameter; if current and proven technologies indicate the possibility to observe a particular parameter and finally; if the satellite operator has plans for such an instrument and mission. Such a methodology will first be applied to the present operational meteorological satellites and then future environmental observation satellites.

Present operational meteorological satellites

At present, soundings of temperature and humidity are the domain of the polar-orbiting meteorological satellite constellation. The reason for this is historical. Sounding instruments were first developed for the polar-orbiting satellites since they flew closer to the Earth and provided a more complete global coverage. However, the present user requirement is for hourly soundings which cannot be satisfied with the present constellation of polar-orbiting satellites. Additionally, there is already proven technology for soundings from geostationary orbit. Finally, there are firm plans to continue at least some of the geostationary satellites with a sounding capability. **Thus, soundings of temperature and humidity should be provided from both constellations of satellites.**

There are several user requirements for wind vector over the ocean surface. The technology has been proven for well over a decade. There are plans to fly operational scatterometers on operational polar-orbiting satellites. **Thus, the operational polar-orbiting satellites should have the capability to provide surface wind vectors over the ocean.**

From a continuity viewpoint, as well as the need for sufficient overlap between geostationary satellites, **there is a need for at least six geostationary satellites.** The definition of five geographical positions (0, 75W, 135W, 140E and 76E) as contained in the 1993 edition of Manual for the Global Observing System was based on the initial commitment by the satellite operators in the 1970's and 80's. That definition provided for neither a sufficient overlap between geostationary satellites nor a robustness in the overall system to allow contingency planning in case one satellite was unable to meet all or part of its mission. Due to the geographical distribution of satellite operators, it is not possible to define an overall system that is evenly spaced. Thus in taking into account the national mandates for the geostationary satellite operators, it is necessary to have at least six geostationary satellites with geographical positions near (0, 75W, 135W, 140E, 105E and 65E).

The concept of requiring a satellite to have the capability of making several different types of concurrent observations, e.g. soundings, imagery and scatterometry from the same polar-orbiting satellite, should be reviewed. It is possible that a series of smaller single purpose satellites would be more cost-effective. Although not yet implemented on operational satellites, the concept has been successfully demonstrated on experimental and single satellite missions.

Future environmental observational satellites – a new constellation

Experimental observation satellites pose unique problems when viewed from the operational need for: open and timely access to experimental data in standard formats; preparation of the community for new data usage, and, data continuity. These issues are under discussion within the Consultative Meetings on High-Level Policy on Satellite Matters. It is expected that a set of guidelines will be developed and agreed upon by the satellite operators. Assuming that such assurances can be obtained, then a new constellation of satellites could be added to the space-based GOS. Certainly, user requirements exist in abundance for parameters not provided by the meteorological satellites including, but not limited to: aerosol, cloud ice, cloud water and trace gas profiles; land cover; land surface topography; ocean wave period and direction; ocean topography, ocean colour; significant wave height; snow water equivalent; soil moisture; and vegetation type. There is now a convergence of needs since the R&D satellite operators have also shown a keen interest for operational evaluations of their new data. The existence of experimental satellite missions capable of measuring these as yet unsatisfied requirements provides ample proof of the availability of technology and plans – although not necessarily for a continuous series of satellites. Thus, the space-based GOS **could add a constellation of experimental satellites** covering several different mission areas such as oceanographic, atmospheric chemistry, high-resolution land use and hydrological. Such a **constellation would require at least four polar-orbiting experimental satellites**. The selected mission areas (oceanography, atmospheric chemistry, high-resolution land use and hydrology) serve as an expedient to group together similar parameters. The parameters listed within **the four mission areas** would support important application areas beyond those of operational meteorology to include **climate change, monitoring and detection, operational oceanography, hydrology and agricultural meteorology.**

It should be recalled that there is a close correspondence between the proposed constellation of experimental satellites and the present or planned IGOS themes. Thus, the dual commitments by WMO for the Integrated Global Observing Strategy and in establishing and maintaining a Global Observing System for WMO and supported programmes are complementary. As noted earlier, the Global Observing System is both internationally agreed-upon and formally constituted through an intergovernmental process, namely through resolutions by WMO constituents bodies. Enhancements to the Global Observing System would require such formal approval if its high-level description was augmented to encompass the four proposed mission areas within a constellation of Research and Development satellites and thus provide the necessary observational data for WMO and supported programmes as well as responding to the needs of the Integrated Global Observing Strategy.

For the following four proposed new missions, requirements already exist and are formally documented for WMO and supported programmes, e.g. GCOS, GOOS and WCRP. The list below summarizes requirements that are not satisfied by the present suite of operational meteorological satellites. In some cases, the operational meteorological satellites do measure the required parameter but not to the specified resolution or accuracy, e.g. tens of metres for the high resolution land use mission for Fractional Photosynthetically Active Radiation (FPAR). In addition to the detailed list of observational requirements for each mission, at least one example is provided where a Research and Development mission is planned. The existence of observational requirements and planned satellite operator missions confirm the three-pillar analysis (existing requirement, proven technology and planned instruments and missions) of the need for a particular mission within the space-based component of the Global Observing System.

Oceanographic mission

Table 1 contains a list of oceanographic requirements not currently measured by operational meteorological satellites. The already launched RADARSAT-1 mission of the Canadian Space Agency (CSA) and its follow-on RADARSAT-2 provide an excellent example of the value of Synthetic Aperture Radar (SAR) data for sea-ice determination. The highly successful TOPEX-POSIEDON mission and a similar planned mission, JASON, for the National Aeronautics and Space Administration (NASA) and the Centre National d'Etudes Spatiales (CNES) clearly demonstrate the ability to measure the ocean surface topography to a few centimetres accuracy. Additionally, the ENVISAT mission of the European Space Agency (ESA) will deploy an Advanced Synthetic Aperture Radar (ASAR) as well as a Radar Altimeter (RA-2).

Table 1
Oceanographic requirements not currently measured by operational meteorological satellites

Dominant wave period and direction
Significant wave height
Ice-sheet topography
Iceberg height and fractional cover
Ocean chlorophyll, yellow substance and suspended sediment concentration
Ocean topography and currents (vector)
Ocean salinity
Sea level
Sea-ice surface temperature

Atmospheric chemistry mission

Table 2 contains a list of atmospheric chemistry requirements not currently measured by operational meteorological satellites. The National Space Development Agency of Japan (NASDA) is considering a mission called the Global Change Observation Mission (GCOM) as part of the space segment In the Global Climate Observing System (GCOS) aimed at performing systematic Earth Observations necessary for researching climate changes. GCOM will carry two atmospheric instruments, the Ozone Dynamics Ultraviolet Spectrometer (ODUS) and the Solar Occultation Fourier transform Spectrometer for Inclined orbit Satellite (SOFIS). The combined suite of instruments will measure total ozone, NO_2, BrO, $ClONO_2$, CH_4 and HCHO.

Table 2
Atmospheric chemistry requirements not currently measured by operational meteorological satellites

Aerosol (total column) size
Aerosol profiles
Trace gas profiles for BrO, CFC 11, CFC 12, CH4, ClO, ClONO2, CO, CO2, HCl, HNO3, N2O, NO, NO2 and OH

High-resolution land use mission

Table 3 contains a list of high-resolution land use requirements not currently measured by operational meteorological satellites. It should be noted that most all of the requirements in Table 3 state horizontal resolution in tens of metres. The already flown and planned missions for the Satellite Pour l'Observation de la Terre (SPOT) by the CNES clearly demonstrate the utility of such data. The VEGETATION instrument found on SPOT-4 and SPOT-5 measures most parameters in Table 3.

Table 3
High-resolution land use requirements not currently measured by operational meteorological satellites

Photosynthetically Active Radiation (PAR)
Fractional Photosynthetically Active Radiation (FPAR)
Leaf Area Index (LAI)
Land cover and surface topography
Soil type
Vegetation type

Hydrological mission

Table 4 contains a list of hydrological requirements not currently measured by operational meteorological satellites. The currently flying Tropical Rainfall Measuring Mission (TRMM) of NASA has already yielded valuable data sets describing cloud structures on a global basis. The Advanced Microwave Scanning Radiometer (AMSR) developed by NASDA and to be flown by both NASDA (ADEOS-2) and NASA (EOS-PM) will measure many of the parameters in Table 4.

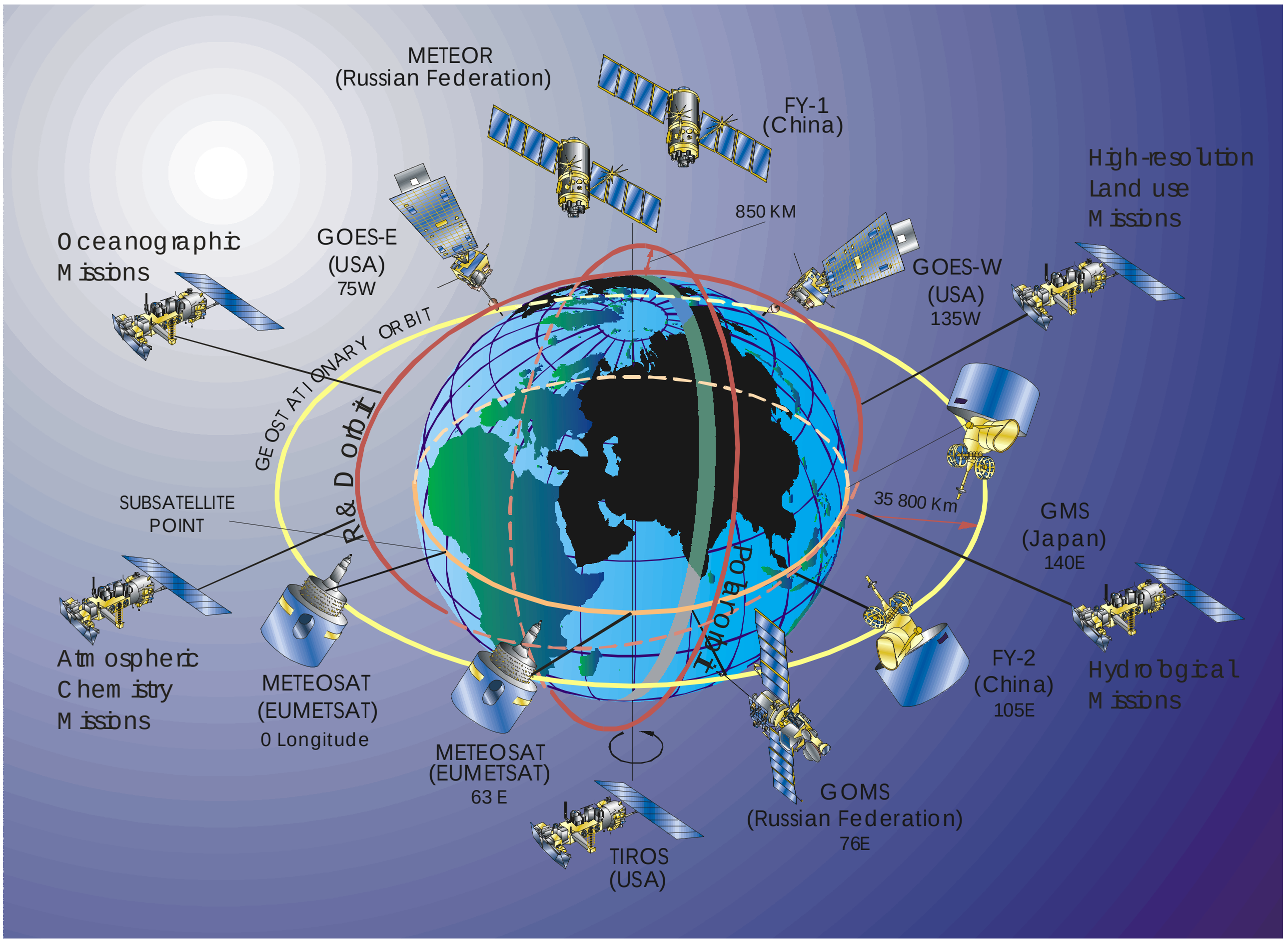
Table 4
Hydrological requirements not currently measured by operational meteorological satellites

Cloud ice profile and total column
Cloud water profile (< 100 µm) and total column
Cloud water profile (> 100 µm) and total column
Glacier cover
Ice thickness
Permafrost
Snow melting conditions
Snow water equivalent
Soil moisture

It should also be noted that there might not be a one-to-one correspondence between a mission area and a satellite. For example, the meteorological satellite operators already have plans to fly as part of their satellite payloads, instruments of direct value to other mission areas such as altimeters for oceanography. **Thus, polar-orbiting and geostationary constellations could be comprised of several multi-purpose and multi-operator satellites as well as smaller single or limited purpose satellites.** Additionally, many of the above noted Research and Development mission would provide data for more than one mission, e.g. ENVISAT with RA-2 (Oceanographic), SAR (Oceanographic), MERIS (High-resolution land use) and MIPAS (Atmospheric chemistry).

One important characteristic of the new constellation of experimental satellites should be a clearly defined transition from research to operational status for those instruments found to be provide a major impact to any application area. It is anticipated that not all research and development instruments would follow such a transition path thus it would be important to be able to identify those research and development instruments early on that should transition to operational status. An early and coordinated transition plan would insure maximum usage of the data.

Finally, CGMS is considered a major success because it provides an operational forum for the exchange of information amongst the satellite operators as well as between them and WMO. The pillar of new satellite providers would have to be accommodated possibly **through an expansion of the CGMS mandate.**



Summary

The space-based component of the Global Observing System has evolved since the formation of WMO's World Weather Watch from first a constellation of polar-orbiting meteorological satellites to a two constellation (polar-orbiting and geostationary) system of operational meteorological satellites. Meanwhile, observational requirements of WMO and supported programmes have greatly expanded especially in the last decade. The most appropriate manner to satisfy the present requirements while recognizing the capabilities of both operational meteorological and Research and Development satellites would be to expand the present definition of the space-based Global Observing System to include a third constellation of Research and Development satellites, complementing the existing two operational meteorological satellite constellations. The expansion of the definition should be through resolution by WMO constituent bodies thus formalizing the high-level system requirements that would provide the necessary observational data for WMO and supported programmes.

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